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A review on test procedure, energy efficiency standards and energy labels for room air conditioners and refrigerator–freezers

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ABSTRACT

Air conditioners and refrigerator–freezers are major energy users in a household environment and hence efficiency improvement of these appliances can be considered as an important step to reduce their energy consumption along with environmental pollution prevention. Energy efficiency standards and labels are commonly used tools to reduce the energy uses for household appliances for many countries around the world. The first step towards adopting energy efficiency standards is to establish a test procedure for rating and testing of an appliance. It may be mentioned that an energy test procedure is the technical foundation for energy efficiency standards, energy labels, and other related programs. This paper reviews requirements and specifications of various international test standards for testing and rating of room air conditioners and refrigerators. A review on the development of the energy efficiency standards has been provided as well. Finally, energy labels that provide some useful information for identifying energy efficient products have been reviewed for these appliances. It may be stated that the review will be useful for the developing countries who wish to develop these energy savings strategies. It is also expected to be useful to revise the existing strategies for a few selected countries who already implemented these strategies earlier.

Contents

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1. Introduction

Energy efficiency standards and labels for household appliances are among the most popular strategy to save energy and educate the consumers to use energy wisely. There are many publications related to standards and labels especially in the developed countries but relatively very little information has been published on this issue on developing countries. Although successful standards and labels have been launched in some western countries, the initiative cannot be directly reproduced in other countries as some of them have unique manufacturing structure, energy policies, culture and climates [1]. The study found that a few countries have failed while some other countries have implemented the programs successfully. Some of the experiences can be directly adopted, but some others must be modified in order to make it suitable for a particular country. For example, for air conditioning, the comfort temperature is quite different among the population on the earth. An acceptable comfort range tend to vary from one country or population to another; generally an acceptable level being higher for acclimatized Asians and Africans compared to the white populations of North America and Europe [2]. However, other appliances such as TV, fan, lamp and bulb can be directly adopted because they are not affected by acclimation condition of the country.

Household appliance standards have a history of more than three-decades, but it became popular just after oil price shock in the 1970s. The United States and European countries claimed that they are the first countries that implemented efficiency standards and labels for household appliances. Egan [1] states that United States is the nation with the oldest standards and labeling programs. From the literatures, it was found that European countries were among the first in introducing legislation to limit the energy consumption of domestic appliances during the 1960s and 1970s. France introduced mandatory minimum energy efficiency standard for refrigerators in 1966 and freezers in 1978. Russia introduced mandatory energy efficiency standards in 1976 while Poland was supposed to have had mandatory energy efficiency standards for a range of electrical appliances from as early as 1962 [3]. It was noted that in North America, the first energy efficiency standards for appliances was established in the state of California in 1980 [4]. Among the South East Asian nations, the Philippines and Thailand are leading the way towards the development of national energy efficiency standards and labels. The two countries have well-established and well-functioning programs for improving the efficiency of household appliances. Other countries that have implemented either standards or labeling or both are Australia, Brazil, Canada, China, Japan, India, Korea, Mexico, Philippines, Taiwan, Thailand, etc. [5,6]. In Malaysia, the Energy Commission has introduced the mandatory energy efficiency standards for ballast and fan on January 1999 and 2001 respectively [8]. Masjuki et al. [9], Saidur et al. [10] and Mahlia et al. [11] also published works on energy efficiency standards and labels for Malaysia extensively. An overview of appliance standards history is tabulated in Table 1 [1,3–15].

Table 1
Overview of appliances standard history.

Year effective	Country	Legal status	Appliances
1962	Poland	Mandatory	Several
1966	France	Mandatory	R
1976	Russia	Mandatory	Several
1979	Japan	Voluntary	RAC/LT/R/FR/TV
1978	Canada	Mandatory	16 product
1989	China	Mandatory	F/R/TV
1980	United States	Mandatory	R/AC/RAC/CW
1991	Taiwan	Mandatory	RAC
1987	Australia	Mandatory	R/RAC/AC/DW/CD/CW
1992	Korea	Voluntary	R/FR/RAC/LT
1993	Philippines	Mandatory	RAC
1994	Thailand	Voluntary	R/RAC
1995	Hong Kong	Voluntary	R/RAC/CW
1999	Malaysia	Mandatory	F/LT

Note: Refrigerator (R), Freezer (FR), room air conditioner (RAC), central air conditioner (AC), cloths washer (CW), cloths dryer (CD), dishwasher (DW), lighting (LT), television (TV) and fan (F).

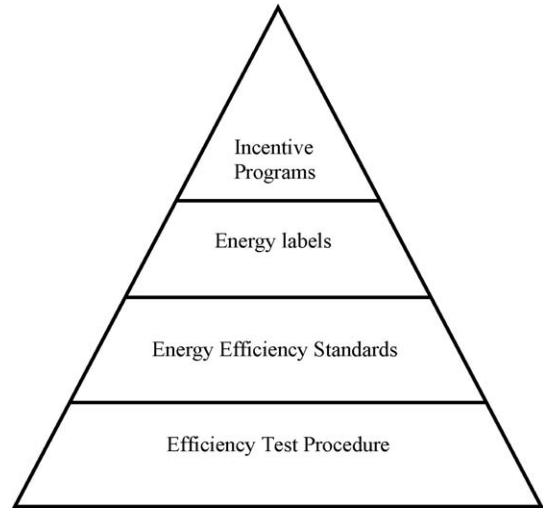

Fig. 1. Relationship among test procedure, standards and labels.

There are four areas related to energy efficiency program for household appliances. These are: (i) energy test procedures, (ii) energy efficiency standards, (iii) energy labels, and (iv) incentive programs. These have been discussed in the following section. The relationship among energy test procedures, standards, labels and incentive programs have been presented in Fig. 1 [16].

It may be mentioned that in the literatures there is no comprehensive works on energy test procedure, energy efficiency standards, labels and incentive program. It is expected that this work will fill that gap. It will be a useful guideline for Government, Policy makers, researchers and many others too.

2. Energy test procedure

The energy test procedure is the foundation of energy efficiency standards, energy labels and other related programs. A test procedure is a well-defined protocol or laboratory test method to provide manufacturers, regulatory authority and consumers (through energy labels) a way of consistently evaluating energy performance of appliances across different brands and models with respect to the characteristic in design and used of the product [16].

The two international entities responsible for appliance energy test procedures are the International Organization for Standardization (ISO) and its sister, the International Electrotechnical Commission (IEC). ISO is a worldwide federation of over 100 national standards bodies mainly focusing on mechanical performance while IEC has 50 national members focusing on electrical performance. They rely on an international network of regional and national standards organizations. In Europe, the European Committee for Standardization (CEN) and its sister organization the European Committee for Electrotechnical Standardization (CENELEC) are the regional equivalents of ISO and IEC, respectively. The Japan Industrial Standards Association (JIS) is responsible for all appliance test procedures in Japan. In the United States, the responsibilities spread among several organizations. While in Malaysia, the standard establishment is the responsibility of the Standard and Industrial Research Institute of Malaysia (SIRIM). The European Union mostly uses the international test procedure

established by the ISO. The United States has her own test procedures. The Canadian and Mexican test procedures are very similar to those used in the United States. Most countries are adopted the ISO test procedure, while few others have their own unique test procedure [4].

According to Ref. [16] a good test procedure should fulfill the following criteria:

(i) reflect actual usage condition;
(ii) yield repeatable, accurate results;
(iii) reflect the relative performance of different design options;
(iv) cover a wide range of models within a category;
(v) produce results that are easy to compare with other test procedures;
(vi) be easy to modify to accommodate new technologies or features; and
(vii) be inexpensive to perform;

Unfortunately, these goals usually conflict with each other. A test procedure that tries to precisely duplicate actual usage will probably be expensive and not easily develop. As a result, an energy test procedure is a compromise. It does not fully cover all of the criteria for an ideal test procedure, but at least a ranking of energy performance of different models is close to the ranking by the models of actual energy performance or field energy use [17].

To develop a satisfactory test procedure is time consuming. For example, in the Philippines, a test standard was developed in 1983, but put on hold during the 1986. Finally in 1994, standards and labels were developed with the collaboration of manufacturers and the government [12]. In the United States, the test procedure was first developed in the late 1970s. However, it became effective in January 1980. After being introduced, the procedure has been revised from time to time, the last was in 1997 [18]. If an internationally recognized test procedure such as ISO standards is adopted, it should not take a long time to establish the test procedure. Essentially, there are three categories of test procedure development [17]. These are:

(i) Development of a unique domestic test procedure.
(ii) Adoption of established international test procedure.
(iii) Adoption of a simplified version of an international test procedure.

Wiel and McMahon [17] suggested to adopt internationally recognized test procedure and there must be strong reasons for not selecting an international test procedure, because a domestic procedure will take longer time to develop and costly to maintain than an international test procedure. If it is not possible, consider simplified versions of internationally recognized tests procedure to lower costs and to avoid technological obstacles. Since the domestic test procedure takes a long time to develop, difficult to maintain and also costly, therefore this option is not preferred [19]. The manufacturers and some countries also have begun to regard country specific test procedures as a trade barrier that should be removed in accordance with World Trade Organization (WTO) agreements. In fact, there are numerous efforts under way to harmonize the appliance test procedure in order to stimulate international trade and reduce the trade barrier [16]. However, some of the conditions in the international test procedure may not applicable in some countries [20]. Thus, it needs careful considerations for selection of energy test procedure.

2.1. Test procedure for air conditioners

The test procedure proposed by ISO for room air conditioners testing and rating for performance is ISO 5151 [21]. There are many test procedures used around the world, however most of the countries have adopted a simplified version of ISO 5151 as a test procedures for room air conditioners. These countries are Singapore with SS 316, Philippines with PNS 240, Sri Lanka with SLS 524 and some other countries [22–24]. Britain and China has adopted ISO 5151 and the countries such as Japan, United States, South Korea and some other countries have developed their own unique room air conditioners test procedure. However, the test conditions for room air conditioners rating that are used in these countries are quite similar to ISO 5151 [14]. The PNS 240-1998 is very similar to ISO 5151 test standard. The differences are the test conditions to determine the cooling capacity and maximum cooling test condition [25]. In the United States presently, several differences exist between the Department of Energy (DOE) test procedure and the ISO 5151 test standards such as the test voltages, test-operating tolerances, and test procedure for frosting [18]. However, there is only a slight difference in the temperature condition. The British Standards Institution (BS 2852: Part 1) is based on three conditions such as A, B and C. A, B, and C of BSI are related to ISO 5151 as T1, T2 and T3, respectively [26]. It was found that the temperatures for both standards were identical. Several other countries have modified ISO 5151 slightly to incorporate local conditions. The resulting differences in test procedure among these countries and ISO 5151 are negligible. The European Standard EN 814, which specifies the terms, definitions and methods for the ratings and performance of air and water-cooled air conditioner, is almost similar to ISO 5151 test standard [27]. Generally, all test standards measure the energy performance of the appliances at the steady-state condition. However, the number of additional measurements and calculations required are different slightly. The test procedure and legal status of energy efficiency standards and labels for room air conditioner around the world are tabulated in Table 2 [5–12,27].

Table 2
Test procedure and legal status of energy efficiency standards and labels for room air conditioner around the world.

Country	Test procedure	Energy Labels		Efficiency standards	
		Mandatory	Voluntary	Mandatory	Voluntary
Malaysia	No^u	No^u	No	No^u	No
Australia	Yes^u	Yes	No	No^u	No
Canada	Yes	Yes	No	Yes	No
China	Yes	No	No^u	Yes^u	No
EU	Yes^u	No^u	No^u	No^u	No^u
Hong Kong	Yes	No^u	Yes	No	No
Indonesia	Yes	No^u	No^u	No	No
Israel	Yes	No^u	No	No	No
Japan	Yes^u	Yes^u	No	No	Yes
Mexico	Yes	Yes	No	Yes	No
New Zealand	Yes^u	No^u	Yes	No^u	No
Philippines	Yes	Yes	No	Yes	No
Russia	Yes	No	No	Yes	No
Singapore	Yes	No	No	No	Yes
South Korea	Yes^u	Yes	No	Yes	Yes
Taiwan	Yes	No	No	Yes	No
Thailand	Yes^u	No^u	Yes	No^u	No
USA	Yes	Yes	Yes	Yes	No

Note: ^{u} = under review.

2.2. Test procedure for refrigerator–freezer

2.2.1. An overview of ISO refrigerator–freezers test standards

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies. ISO 8187 [28], ISO 8561 [29] and ISO 7371 [30] are the relevant standards for testing the energy consumption of household refrigerator–freezers having two or more compartments. At least one compartment (the fresh food storage compartment) is suitable for storing unfrozen food, and at least one compartment (the food freezer compart-

Table 3
Summary of requirements international test procedure [32,43].

Variable	ANSI/AHAM	ISO	AS/NZS 4474.1-97	CAN/CSA-C300-M91	GB 12021.2-89	JIS C 9607	KS C 9305-96	NOM-015-ENER-97	CNS 2062-95
Energy consumption ambient temperature	$32.3 \pm 0.6\,^{\circ}C$	$25 \pm 0.5\,^{\circ}C$	$32 \pm 0.5\,^{\circ}C$	$32.2 \pm 0.6\,^{\circ}C$	$25 \pm 0.5\,^{\circ}C$	$15/30 \pm 1\,^{\circ}C$	$30 \pm 1\,^{\circ}C$	$32.2 \pm 0.6\,^{\circ}C$	$30 \pm 1\,^{\circ}C$
Energy consumption fresh food temperature	$3.3/7.22\,^{\circ}C$	$5\,^{\circ}C$	$3\,^{\circ}C$	$3.3/7.22\,^{\circ}C$	$5\,^{\circ}C$	$3 \pm 0.5\,^{\circ}C$	$3 \pm 0.5\,^{\circ}C$	$3.3/7.2\,^{\circ}C$	$3 \pm 0.5\,^{\circ}C$
Energy consumption freezer temperature	$-15/-17.8\,^{\circ}C$	$-18\,^{\circ}C$	$-15\,^{\circ}C$	$-9.4/-15/-17.8\,^{\circ}C$	$-18\,^{\circ}C$	$-6/-12/-18\,^{\circ}C$	$-6/-12/-18\,^{\circ}C$	$-9.4/-15/-17.8\,^{\circ}C$	$-6/-12/-15/-18\,^{\circ}C$
Freezer for energy consumption	Sometimes loaded	Loaded	Unloaded	Sometimes loaded	Loaded	Sometimes loaded	Sometimes loaded	Sometimes loaded	Loaded
Operation test ambient temperatures	$21.1/32.2/43.3\,^{\circ}C$	$16/32\,^{\circ}C$	$10/32/43\,^{\circ}C$	None	$16/32\,^{\circ}C$	$15/30\,^{\circ}C$	$15/30\,^{\circ}C$	None	$15/30\,^{\circ}C$
Operation test fresh Food temperatures	1.1 to $5\,^{\circ}C$	0 to $5\,^{\circ}C$	0.5 to $6\,^{\circ}C$	None	0 to $5\,^{\circ}C$	≤ 2 or $\leq 5\,^{\circ}C$	$\leq 5\,^{\circ}C$	None	$\leq 5\,^{\circ}C$
Operation test freezer temperatures	$\leq -15/-17.8\,^{\circ}C$	$\leq -18\,^{\circ}C$	$\leq -15\,^{\circ}C$	None	$\leq -18\,^{\circ}C$	$\leq -18/-12/-6\,^{\circ}C$	$\leq -18/-12/-6\,^{\circ}C$	No	$\leq -18/-15\ -12/-6\,^{\circ}C$
Pull down test	Yes	No	Yes	No	No	Yes	Yes	No	Yes
Freezing capacity test	No	Yes	No	Chest and upright freezers only	Yes	Yes	Yes	No	Yes
Ice-making capacity	Yes	Yes	Yes	No	Yes	No	No	No	No
Temperature rise time	No	Yes	No	No	Yes	No	No	No	No
Other performance tests	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes
Gross volume	Not specified	Total only (not specified at sub-compartment level)	Compartment (including sub-compartment)	Not specified	Total only (not specified at sub-compartment level)	Not specified	Not specified	Not specified	Not specified
Storage volume	All levels	All levels	All levels	All levels	All levels	All levels	All levels	All levels	All levels
Volume used for MEPS and energy labeling	Storage	Storage in EU	Gross	Storage	Storage in EU	Storage	Storage	Storage	Storage
Freezer compartment adjustment factor (adjusted volume)	1.63	2.15	1.6	1.63	2.15	NA	NA	1.63	1.778
Separate freezer energy adjustment	0.7/0.85	No	No	0.7/0.85	No	No	No	0.7/0.85	No
Energy sources and refrigeration systems covered	All electric A.C. single phase systems	Any	Mains powered electric vapour compression	All electric A.C., 60 Hz, 110 V within volume limits	Any	Mains powered electric vapour compression	Mains powered electric vapour compression with volume limits	All electric A.C., 60 Hz, 115 V	Mains powered electric vapour compression with volume limits
Humidity	Not specified	45–75%	Not specified	Not specified	45–75%	$75 \pm 5\%$	$75 \pm 5\%$	Not specified	$75 \pm 5\%$
Anti-sweat heaters during energy-consumption tests	Average on and off	Only when needed	On	Average on and off	Only when needed	On	On	Average on and off	On
Door openings	No	No	No	For variable defrost systems 23	No	Every 12 min, 50 times	No	No	No

ment) is suitable for freezing fresh food and for the storage of frozen food at −18 °C or lower. ISO specifies the following four climatic zones and their ambient temperatures as:

1. Extended temperature zone: 25 ± 0.5 °C.
2. Temperate zone: 25 ± 0.5 °C.
3. Subtropical zone: 25 ± 0.5 °C.
4. Tropical zone: 32 ± 0.5 °C.

According to the ISO standard, the test period shall be at least 24-h long with no door openings. Relative humidity should be kept within 45%-75% inside the chamber. An excellent overview of these standards has been summarized in Ref. [31–32] as well.

2.2.2. Australian–New Zealand Standard (ANZS)

AS 1430-1986 [33] and NZS 6205.2-1989 [34] are the relevant Australian–New Zealand Standards for testing energy consumption in household refrigerators. These standards were issued as Joint Standards under the terms of the Memorandum of Understanding between the Standards Association of Australia and the Standards Association of New Zealand, with the objective of reducing technical barriers to trade between the two countries. Therefore, the New Zealand Standards and the corresponding Australian standards are comparable although some differences do occur. These standards are being reviewed and may possibly be issued with new numbers in future, but are unlikely to change the test conditions. The cabinets were tested at 32 °C and 75 ± 5% relative humidity because other standards, except ISO, require relative humidity at this level.

Test period: The energy consumption shall be measured until either at least 1 kWh of energy is consumed or the refrigerator has operated for at least 16 h, whichever is less. The test period shall include only whole control cycles. For an automatic defrost refrigerator, the energy consumption shall be measured from a point in one defrost cycle to a corresponding point in the next or multiple of that defrost cycle, until either at least 1 kWh of energy is consumed or the refrigerator has operated for at leasl 16 h whichever is less.

Door openings: No door openings are specified in ANZS.

2.2.3. American National Standard (ANS)

ANSI/AHAM HRF-l-1988 [35] is the relevant American National Standard that contains the energy-consumption test for refrigerators. This standard was developed by the Association of Home Appliance Manufacturers (AHAM) and was approved by the American National Standards Institute (ANSI). The ambient conditions were set to 32.2 °C and 75 ± 5% relative humidity for all the tests.

Test period: The test must run for at least 3 h but not longer than 24 h. During the test period, the compressor has to complete two or more whole control cycles, If incomplete cycling (less than two compressor cycles) occurs during a 24 h period, the results of the 24 h period are to be used.

Door openins: No door openings are specified in ANS.

2.2.4. Japanese Industrial Standard (JIS)

JIS C 9607-1986 [36] is the relevant standard that specifies the requirements for the determination of energy consumption of refrigerators. The ambient temperature shall be 15 and 30 °C in two different tests while the relative humidity shall be 75 ± 5%.

Test period: The measuring period shall be 24 h.

Door openings: The doors of a cabinet shall be opened and closed during the first 10 h from the commencement of measurements as specified in Table 1.

2.2.5. Chinese National Standard (CNS)

CNS206212 [37] and CNS957713 [38] are the relevant Chinese standards that cover test methods for electric refrigerators and freezers. All the cabinets were tested under ambient temperatures of 30 ± 1 °C and relative humidity of 75 ± 5%.

Test period: The energy consumption shall be measured for 24 h.

Door openings: No door openings are specified in CNS.

Summary of standards.

The temperature and energy consumption requirements for various test standards are summarized in Tables 2 and 3, respectively.

Test standard in Brazil [39].

ISO test with 32 °C and 50% relative humidity.

2.2.6. Korean test procedure

The Korean test procedure, KS C 9305-96 [40] *Household electric refrigerators, refrigerator–freezers and freezers* is NEQV to JIS C 9607 C-93 [36] which is itself influenced by the ISO test procedures (ISO 5155, ISO 7371, ISO 8187 and ISO 8561).

The Korean standard differs from ISO in the following main respects:

- The ambient temperature used during the energy test is 30 °C.
- Frozen food compartments in no frost refrigerator–freezers are not loaded during energy consumption testing.
- There is no temperature rise time test.
- There is a freezer pull down test and compulsory noise performance limits.

The detailed elements of and differences between the KS C 9305-96 procedure and the ISO and ANSI/AHAM test procedures are indicated in Table 3.

2.2.7. Mexican test procedure

NOM-015-ENER-97 [41]: Energy efficiency of household electric refrigerators and freezers specifies the test procedure. The latter is harmonised with the US DOE test procedure given in CFR Part 430 Subpart B based on ANSI/AHAM HRF-1-1988 and CAN/CSA-C300-M89. The test procedure is significantly different to the equivalent ISO test procedures: ISO 5155, ISO 7371, ISO 8187 and ISO 8561. The main differences from ISO can be summarised as follows:

- NOM-015-ENER-97 does not use the star system to rate frozen food compartments in terms of their design operating temperature and freezing performance.
- NOM-015-ENER-97 has no operating temperature performance requirements.
- Freezing capacity is not tested for any type of freezer compartment.
- The ambient test temperature used during the energy test is 32.2 °C (almost equivalent to ISO conditions for tropical class appliances).
- Frozen food compartments are only loaded (75% full) during energy consumption testing for freezers and for non-frost free systems (no frost systems are not loaded during testing).
- The mean compartmental temperatures during the energy test are different.
- A post hoc adjustment factor is applied to the measured energy consumption of freezers to make the values more representatives of in-use values.
- There are no rise time nor ice-making capacity tests.
- Gross volume is not measured.
- Door openings are included.

The detailed elements of and differences between the NOM-015-ENER-97 test procedure and the ISO test procedures are indicated in Table 3.

Table 4
Summary of requirements of energy test procedure for selected international standards [32,43].

	AS/NZS	ISO	ANSI/AHAM	JIS	CNS
Installation of the refrigerator	Such that any shielding on either side of the cabinet is 300 ± 10 mm	On a wooden platform	Such that the distance from the wall is ≥254 mm	–	See manual$_{12}$
Stable operating conditions	$\Delta T_{FF} \leq 0.5$ °C/6 h $\Delta T_{FR} \leq 0.5$ °C/6 h Over more than two cycles	$\Delta T_{FF} \leq 0.5$ °C/24 h $\Delta T_{FR} \leq 0.5$ °C/24 h	$\Delta T_{FF} \leq 0.023$ °C/h $\Delta T_{FR} \leq 0.023$ °C/h		$\Delta T_{FF} \leq 1$ °C/24 h $\Delta T_{FR} \leq 1.25$ °C/24 h
Humidity	Needs not to be controlled Ambient temperature	45–75%	Needs not to be controlled	75 ± 5%	75 ± 5%
Max vertical temp gradient	1 °C/m from floor to 2 m height	2 °C/m from platform to 2 m height	0.9 °C/m from 51 mm above the floor	3 °C from 50 mm above the floor	3 °C from 50 mm above the floor to 2 m height
No. of *M* points	1	3	2	1	1
Location of *M* points	250–350 mm from the front mid-height position	350 mm from the side/front walls	915 mm above the floor and 254 mm from the centre of the two sides	Either side of refrigerator to get a mean value	See manual$_{12}$
Calculation	$T_A = T(T_{A1})_a$ Fresh food compartment	$T_A = T(T_{A1}, T_{A2}, T_{A3})_a$	$T_A = T(T_{A1}, T_{A2})_a$	$T_A = 1/2(T_{Amax} + T_{Amin})$	$T_A = 1/2(T_{Amax} + T_{Amin})$
No. of *M* points	3	3	3	3	1
Compartment temperature	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$, i.e. mean of the average of all measured temperatures at that point	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$ with $T_{FFi} = 1/2$ $(T_{FFimax} + T_{FFimin})$ where i = 1, 2, 3	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$ with $T_{FFi} = 1/2(T_{FFimax} + T_{FFimin})$ where i = 1, 2, 3	$T_{FF} = (1/2)T(T_{FFmax} + T_{Amin})$ i.e. mean of the highest and the lowest recorded temperature
Test load	No	Yes (100%)	Yes (75%); no load in automatic defrost models	No	No

Table 5
Status energy efficiency standards and labels around the world.

Product	Mal	Chi	Tai	HK	US	Jap	Kor	Phi	Sin	Tha	Can
Air conditioner	–	S	S&L	L	S&L	S&L	S&L	S&L	S	L	S
Refrigerators	–	S	S&L	L	S&L	L	S&L	–	–	L	S&L
Central AC	–	S	S	–	S&L	–	S&L	–	–	–	S&L
Clothes Washers	–	S	L	–	S&L	–	–	–	–	–	S&L
Clothes dryers	–	–	S	–	S&L	–	–	–	–	–	S&L
Dishwashers	–	–	S	–	S&L	–	–	–	–	–	S&L
Water heaters	–	–	S	–	S&L	–	–	–	–	–	S&L
Ranges/Oven	–	–	S	–	S&L	–	–	–	–	–	S&L
Fans	S	S	–	–	–	–	–	–	–	–	–
Rice cookers	–	S	–	–	–	–	–	–	–	–	–
Irons	–	S	–	–	–	–	–	–	–	–	–

Note: S = standards; L = labels; Chi = China, Tai = Taiwan, HK = Hong Kong, US = United Stated, Jap = Japan, Kor = Korea, Phi. = Philippines, Sin. = Singapore, Tha = Thailand, Can. = Canada and Mal = Malaysia.

2.2.8. Canadian test procedure

The Canadian test procedure, CAN/CSA-C300-M91 [42] *Capacity measurement and energy-consumption test methods for refrigerators, combination refrigerator–freezers, and freezers* is based on ANSI/AHAM HRF-1-1988. The test procedure is significantly different to the equivalent ISO test procedures: ISO 5155, ISO 7371, ISO 8187 and ISO 8561. The main differences from ISO can be summarised as follows:

- The CAN/CSA-C300-M91 standard does not use the star system to rate frozen food compartments in terms of their design operating temperature and freezing performance.
- The CAN/CSA-C300-M91 standard has no operating temperature performance requirements.
- Freezing capacity is only tested for chest and upright freezers (not freezer compartments in refrigerator–freezers).
- The ambient test temperature used during the energy test is 32.2 °C (almost equivalent to ISO conditions for tropical class appliances).
- Frozen food compartments are only loaded (75% full) during energy-consumption testing for freezers and for non-frost free systems (no frost systems are not loaded during testing).
- The mean compartmental temperatures during the energy test are different.
- A post hoc adjustment factor is applied to the measured energy consumption of freezers to make the values more representative of in-use values.
- There are no rise time nor ice-making capacity tests.
- Gross volume is not measured.
- Door openings are included for units with variable defrost control.

Summary of requirements for test procedures are shown in Tables 3 and 4.

3. Energy efficiency standards

Energy efficiency standard is the prescribed energy performance of a manufactured product, sometimes prohibiting the

manufacturer of products with less energy efficiency than the minimum standards [44]. Energy efficiency standards can be either mandatory or voluntary. A mandatory energy efficiency standard is generally the most effective strategy of rapidly improving the energy efficiency of appliances. While voluntary standards is implemented by negotiated between the government and manufacturers, is an alternative option and have merit of being less controversial and hence easier to enact but do not work well in some countries [6]. The status of energy efficiency standards and labels around the world are tabulated in Table 5 [3–8]. Figs. 2 and 3 show the influence of standard on refrigerator–freezers energy consumption.

According to Ref. [46], standards can be implemented by two methods, i.e. (i) the empirical, and (ii) the technical method. The empirical method is based on the fact that after implementation, a certain percentage of appliances with a reasonable level of efficiency will be eliminated. The technical method is more comprehensive and time consuming because the standards are based on engineering analyses and the technical savings potential. However, it was found that the methods used were similar to the statistical and the engineering/economic approaches given by Refs. [14,17,47]. Another approach that not very popular is consensus approach. This approach was used in the United States in establishing the first national efficiency standards in 1987 [48].

The *statistical approach* is based on the market research and requires fewer data and less analysis than the engineering/economic approach. The data required is the current characterization of the marketplace for the products of interest, i.e. the number of models by efficiency rating currently available in the market. This approach looks at the models available at a particular time and a regression analysis is conducted to determine the correlation of energy used with respect to capacity. By using the approach, the percentage of models that are willing to be eliminated and the desired overall energy savings from the standards can be decided [14]. After the regression line is determined, the least energy efficient model that is above regression line (below average) is eliminated from the market. The energy savings are calculated based on percentage and the total number of appliance eliminated [49]. The method to calculate potential savings for the programs is discussed extensively in Refs. [15,50,51].

This approach is also known as short-term approach to establish energy efficiency standard as per European Union [3]. The statistical method is based on market research of the given appliance. The statistical approach requires fewer data and less analysis than the engineering/economic approach. The data required are those, which give a current characterization of marketplace for the products of interest. A standard level can then be selected after a decision is made as to the energy savings goal and or the number of models that it is acceptable to eliminate from the current marketplace. This approach looks at the models available at a particular time and performs a regression analysis to determine the dependence of energy use on adjusted volume (*An adjusted volume is the sum of the volumes of the different compartments weighted by the difference in temperatures between interior of the compartment and the ambient temperature*). After calculation of the regression line, i.e. reference line, desired goal such as 5 and 10% energy savings lines are drawn from the reference line. The minimum efficiency line or reference line is defined as the line of maximum efficiency index. The efficiency index of a model is the percentage that the energy is above or below the reference line. The efficiency index can be explained by the following equation:

$$I_{eff} = \frac{E_a}{E_{ref}} \tag{1}$$

An energy efficient appliance is located by a point below the reference line and therefore has an index lower than 1. A less efficient appliance has a point above the reference line and an index value greater than 1 as shown in Fig. 4. This approach has been utilized in the European Union (EU) and in Australia. Principle used for defining minimum efficiency line is as follow.

Minimum efficiency standards will prohibit the least energy efficient units from the market. The manufacturers will have to improve or replace the energy efficiency of given models within the time allowed before prohibition comes into force. In reality,

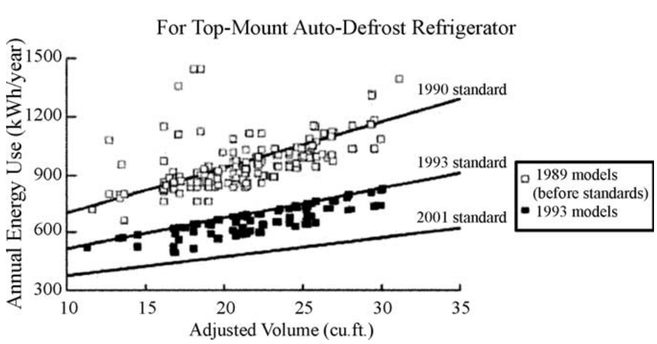

Fig. 2. Refrigerator standards' effect on pool of available new Top-Freezer models [45].

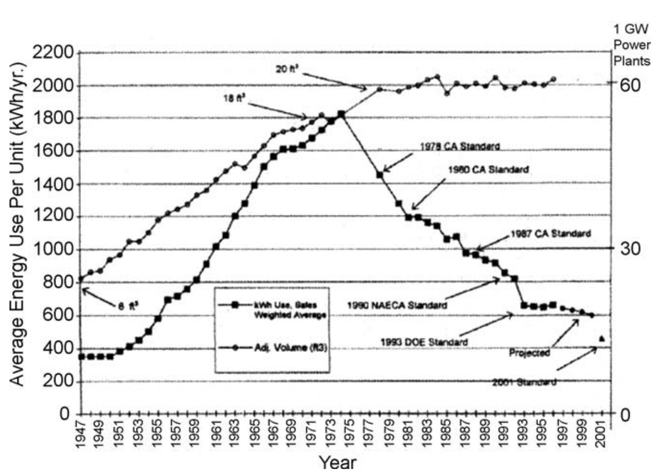

Fig. 3. Historic changes in average UEC and interior volume of new domestic refrigerators [45].

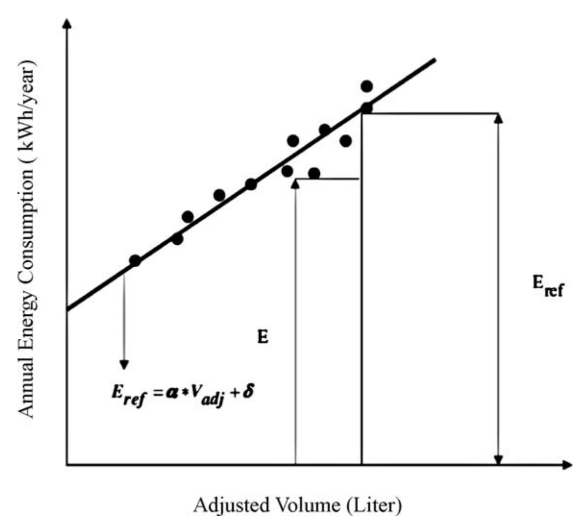

Fig. 4. Refrigerator–freezer energy consumption as a function of adjusted volume [52].

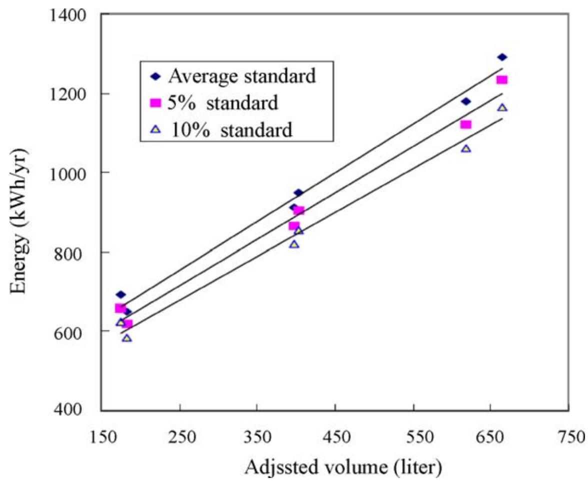

Fig. 5. Annual energy consumption vs. adjusted volume.

poorly efficient units located above the cloud points will be phased out and replaced by a unit with lower efficiency index.

Hence, minimum efficiency standards are defined as a linear equation above which all units are forbidden from the market [52].

Standard Energy-Consumption Equations: With the current average standard, 5% standard, and 10% standard, energy consumption as a function of adjusted volume can be expressed by the following equations:

$$E_{\max} = \alpha \times V_{adj} + \delta \tag{2}$$

$$V_{adj} = \sum V_c \times W_c \times F_c \tag{3}$$

$$W_c = \frac{T_a - T_i}{T_a - T_{rf}} \tag{4}$$

Energy consumption for different standards with different adjusted volume is shown in Fig. 5 as an example.

Significance of Using Adjusted Volume: Refrigerator–freezers' energy consumption depends on the appliance volume and on the temperature difference between the surroundings and the inside of the refrigerator–freezers. The adjusted volume is a measure of the refrigerator–freezers volume adjusted to reflect the various operating temperatures of different compartments.

The *engineering/economic approach* has been widely used by Lawrence Berkeley Laboratory for setting energy efficiency standards in the United States. This approach is more complicated than statistical approach. The analysis is determined the potential efficiency improvements, cost improvement and the impact on the appliance cost through economic analyses, including life cycle cost and payback period [17]. In contrast to the statistical approach, one of the advantage of engineering/economic approach allows for consideration of new design that are not already included in existing models or some combination of design that has higher efficiency improvement than any existing models. Potential disadvantages are the data for efficiency improvement and cost of the projected models are difficult to collect and may be subject to significant uncertainty because it has not been mass-produced yet [14]. Essentially, the following seven steps are the basis for an engineering analysis [17,44,47]: (i) selection of the appliance classes; (ii) selection of the baseline units; (iii) selection of the design options for each class; (iv) calculation of efficiency improvement from each design option; (v) calculation of efficiency improvements for combine design options; (vi) develop cost estimates (include installation and maintenance) for each design option; (vii) determination of the cost-efficiency curves. Once these steps are completed, it is possibly to analyze the economic impact of the potential efficiency improvement on the consumers by carrying out a life cycle cost analyses and payback periods.

There are several parts to an engineering analysis, which have been widely used by Lawrence Berkeley Laboratory (LBL) for the U.S. Department of Energy. Firstly, an engineering analysis is carried out for each product type to determine manufacturing costs for improving the efficiency of a baseline model [1].The following seven steps form the core engineering analysis:

(i) selection of appliance classes;
(ii) selection of baseline units;
(iii) selection of design options for each class;
(iv) calculation of efficiency improvement from each design option;
(v) combination of design options and calculation of efficiency improvements;
(vi) developing cost estimates for each design option;
(vii) generation of cost-efficiency curves.

Life cycle cost analysis: One measure of the effect of proposed standards on consumers is the change in operating cost as compared to the change in purchase price, both resulting from standards. This is quantified by a difference in life cycle cost (LCC) between the base and standards case for the appliance analyzed. Life cycle cost is analyzed as a function of five variables: discount rate, fuel price, appliance lifetime, incremental price and incremental energy savings. The frequency of occurrence of the minimum LCC at each design option determines the optimum efficiency level [53].

The LCC is the sum of the purchase price and the operating expense discounted over the lifetime of the appliance. It can be defined by following equation.

$$\text{Life cycle cost (LCC)} = \text{Purchase price} + \text{NPV} \times (\text{Energy cost per year}) \tag{5}$$

Where,

$$\text{Net present value} = \text{NPV} = \frac{1}{r}\left\{1 - \frac{1}{(1+r)^N}\right\} \tag{6}$$

Payback period: The payback period measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. Payback period (PAY) can be defined by following equation.

$$\text{PAY} = \frac{\Delta PC}{\Delta OC} \tag{7}$$

The payback period is the ratio of the increase in purchase price (ΔPC) from base case to the standards case to a decrease in the annual operating costs (ΔOC). A payback period greater than the lifetime of the product means that the increased purchase price is not recovered in reduced operating costs. A payback period greater than its lifetime is not economically viable for energy efficiency improvements [54].

The *consensus approach* used less formal process to establish standards. In this approach, usually two or more groups get together and decide the standards through a joint process. These groups could be some combination of a government regulatory agency, environmental/consumers groups and room air conditioner manufacturers. This approach was used in the United States in establishing the first national efficiency standards that were incorporated into law in 1987 [48]. The similar approach is also used in Japan where the standards are set by a group of industry and government participants using limited analyses but

knowledgeable about the market and the availability of technologies for a particular product [13].

4. Energy labels

The energy label is usually served as a complement to the energy efficiency standards. The purpose of introducing energy labels is to convince the consumers to buy and manufacturers to produce energy efficient appliances. An energy label is a mandatory or voluntary sticker that is affixed to products and their packaging containing information on the energy efficiency or energy consumption of the product [12]. According to Ref. [55], the main purpose of introducing energy labels are to:

(i) Encourage consumers to select the appliance that uses the least energy and which meets their energy service needs.
(ii) Enable consumers to take account of the operating energy cost of an appliance and to minimise the total life cycle cost of the appliance where possible.
(iii) Encourage manufacturers and importers to improve the energy efficiency of products that they supply to the market.

Energy efficiency improvements of the product through energy efficiency standards and labels are essential for market transformation. The product distributions of the market transformation due to mandatory minimum energy efficiency standards and labels are discussed in Refs. [56–58]. The distributions of appliance as a function of energy efficient products normally correspond to a normal distribution curve. The appliance efficiency is forcing from the present average towards the standards average efficiency that causes transformation in the market. Meanwhile, introducing energy labels is encouraging the availability of more efficient products which also caused transformation in the market. It is expected consumer will purchased the more efficient models from the market due to the labels. This will pull the availability of the high efficient models in the marketplace. Therefore, the product distribution is represented by three bell curves which is presented in Fig. 6 [59].

The main propose of the programs whether voluntary or mandatory is to remove energy inefficient product from the marketplace. In many cases, mandatory requirements are more effective [60]. The reason is under voluntary program the manufacturers that produce inefficient product tend to not declare energy efficiency of their appliances by affixed labels. If inefficient products have no labels in the market, many consumers who might avoid these products if they had all the information will end up

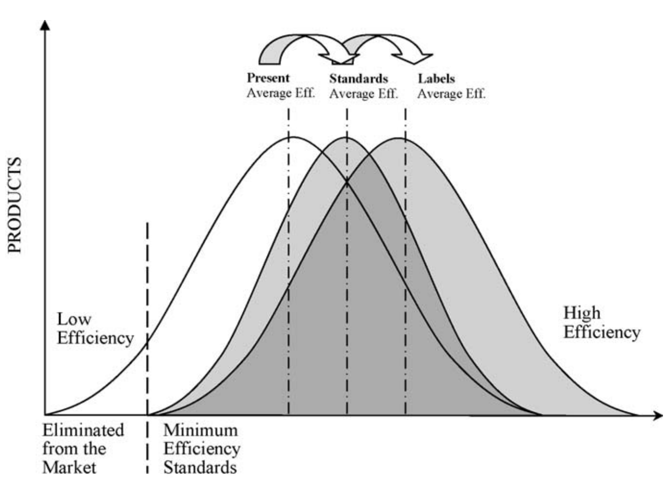

Fig. 6. Expected market transformation of products distribution due to standards and labels implementation.

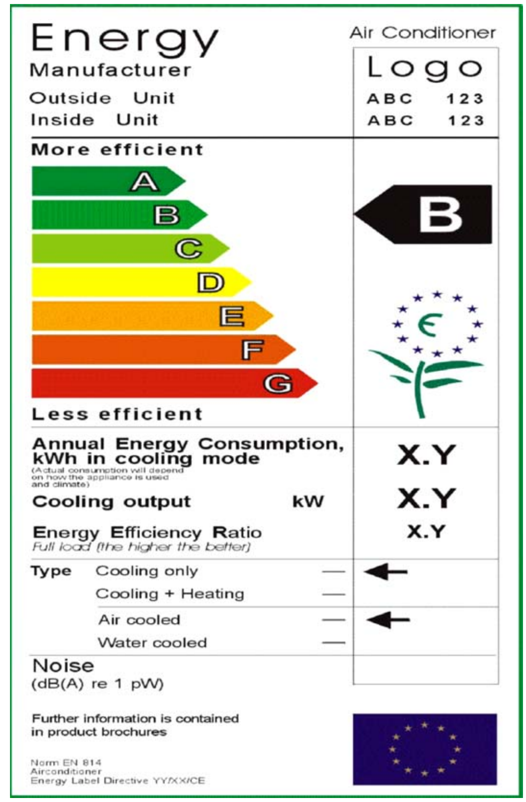

Fig. 7. Comparative category energy labels (EU labels).

buying them. Ultimately, energy labels work effectively if all products are labelled and if consumers can easily distinguish between inefficient, averages, higher and highest efficiency products and this can be achieved by introducing energy labels as mandatory programs [17].

There are three categories of energy labels used in various countries that are: (a) endorsement, (b) comparative, and (c) information-only [17]. *Endorsement labels* offer essentially a "seal of approval" that a product meets certain pre-specified criteria. They are generally based on a "yes–no" procedure and offer little additional information. One example of an endorsement label for energy efficiency is the energy star label which is the energy star label provided by EPA's (US Environmental Protection Agency). A *Comparative labels* is divide in two subcategories: one uses a categorical ranking system; the other uses a continuous scale or bar graph to show relative energy use. The *categorical labels* use a ranking system that telling the consumers how energy-efficient of a model is compared to other. The main emphasis is on establishing clear categories so that the consumer can easily understand, by looking at a single label, how energy-efficient of a product relative to others in the market. The sample of categorical labels is European energy label which is presented in Fig. 7 [61].

The *continuous-scale labels* provide comparative information that allows consumers to choose between models, but do not use specific categories. The sample of this label is the Canadian energy guide which is presented in Fig. 8 [62]. The *Information-only* labels provide information on the technical performance of the single labeled product and offer no simple way (such as a ranking system) to compare energy performance between products. These types of labels are generally not consumer-friendly because they contain only technical information. The sample of the label is shown in Fig. 9 [61].

It is important to keep a consistent label style and format across product types. This is easier for consumers to understand one type

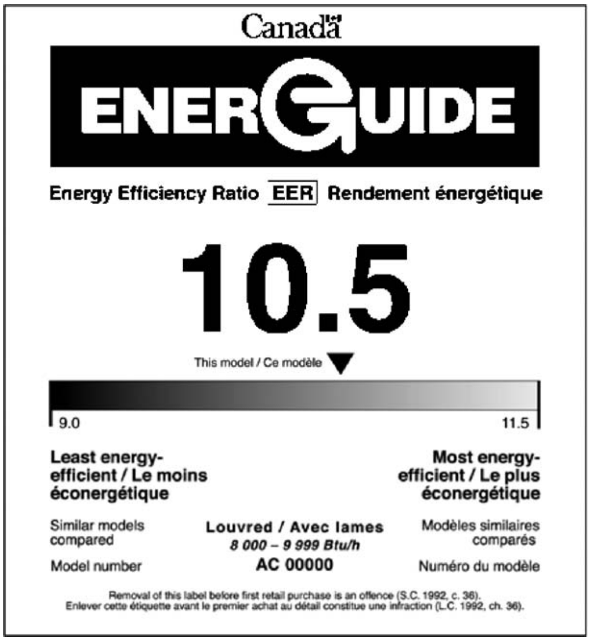

Fig. 8. Continuous-scale labels (Canadian label).

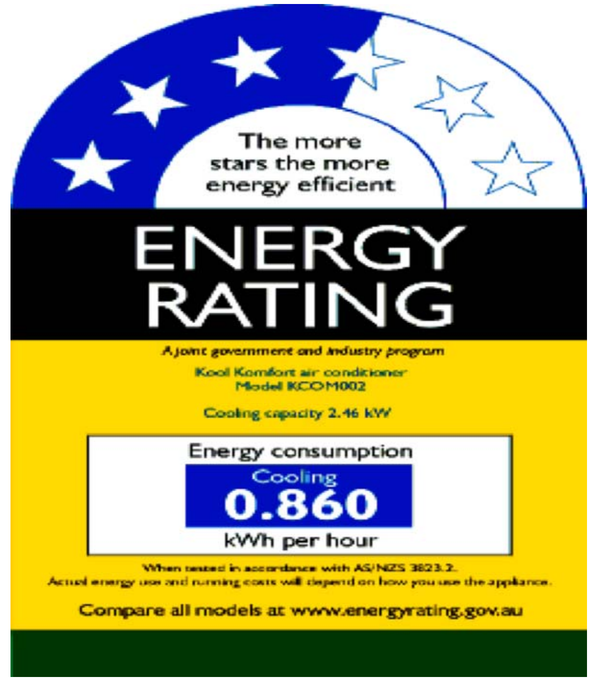

Fig. 10. Australian-style label.

of labels to evaluate different products. To select which label to use is not always easy. It certainly depends on local consumer knowledge and attitudes. Endorsement label is quite effective, at least with a segment of consumers. Categorical comparison labels provide more information about energy use and if well designed and implemented, can provide a consistent basis for buyers to focus on energy efficiency from one purchase to another. Continuous-scale labels can transmit more detailed information on relative energy use, but research has shown that this label format may be difficult for consumers to understand [1,63,64]. Information-only labels are generally effective only for the most educated and economically and/or environmentally concerned consumers. They do not allow easy comparison with other models in the market. The method of development energy labels and calculating its impact is discussed by Refs. [65–67].

Most of the countries had selected a comparative label for implementing energy efficiency standards and labels, therefore it is useful to review the format of similar energy labels that are currently being used in most countries around the world. The basic formats in use around the world for comparative labels can be grouped into three basic styles which are (i) Australian-style label, (ii) European-style label and (iii) U.S.-style label [17].

The *Australian-style label* is having a square/rectangular base with a semi-circle or "dial" across the top. The "dial" resembles a speedometer or gauge, the further advanced the gauge is in the clockwise direction, the better the product. This type of label is

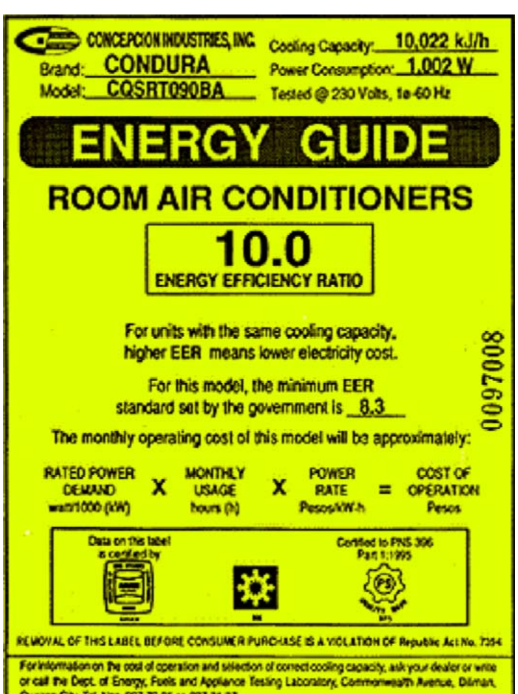

Fig. 9. Information-only energy (Philippines energy guide label).

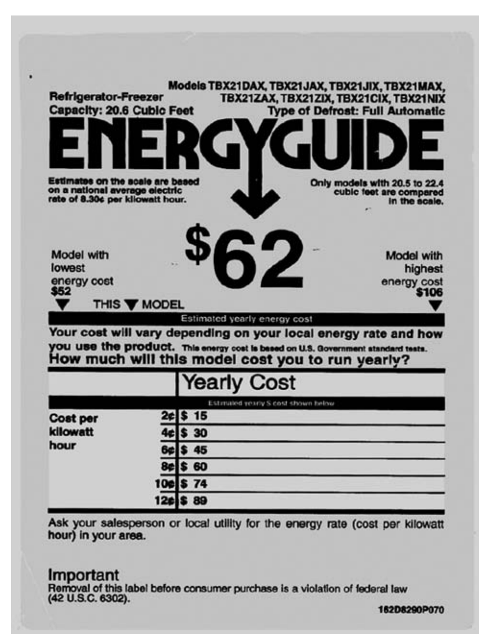

Fig. 11. U.S.-style label.

used in Australia, Thailand, and South Korea and is proposed for India. The number of stars or the "grading" numeral on the scale depends on the energy performance that the model is able to meet (there are five, six, or seven rankings). The samples of Australian-style label presented in Fig. 10 [55].

The *European-style label* is a vertical rectangle with letters ranging from A (best) near the top of the label to G (worst) at the bottom. There is a bar next to each letter: e.g., short and green for A and long and red for G. All seven grade bars are visible on every label. The grade of the product is indicated by a black arrow marker located next to the appropriate bar (e.g., for a C-grade product the marker carries the letter C and is positioned against the C bar). Because of European Union language requirements, the label is in two parts. The right-hand part, which shows the data, is not language specific and tends to be affixed or supplied by manufacturer. The left-hand part, which gives the explanatory text, is language specific and tends to be supplied and affixed in the country of sale. This label is used throughout Western Europe and in some countries of Eastern Europe. Iran uses a variant of the European-style label that is a mirror image because of the direction of Persian script and uses numerals rather than Roman script letters for rankings: i.e. 1 (best) to 7 (worst). Brazil also uses a European-style label. The sample of European-style label is presented in Fig. 7 [61].

The *U.S.-style label* shows energy cost (based on the national average energy tariff). It also has a linear scale indicating the highest and lowest energy use of models on the market and locates the specific model on that scale. This type of label is used in the U.S. and Canada, where labels are now technically but not visually harmonized (e.g., U.S. labels show energy costs, and Canadian labels do not) [63,64]. In both cases, use of monetary units (dollars) was abandoned in favour of physical units (i.e. kWh or efficiency) because variability in energy prices causes labels based on outdated prices to be misleading. The samples of U.S.-style label presented in Fig. 11 [64].

The energy labels for room air conditioners used in several other countries are presented in Figs. 12 and 13. The literatures showed that only two types of energy labels work effectively. First, the letter grade energy labels which was introduced in the European Union countries, Iran and Brazil and second, the star or number type of energy labels that have been used in Thailand, Australia, and India.

Fig. 12. Comparative categorical (Hongkong labels).

Fig. 13. Comparative categorical (Thailand Labels).

5. Incentive programs

There are only two categories of implementation of incentive program namely (i) incentive program for manufacturer and (ii) incentive program for consumers. Some of the incentive programs are implemented with a conjunction of standards and labels and some other can be implemented independently. By introducing incentive programs, it is expected that the optimum impact of energy efficiency programs in this country can be achieved. The two categories of incentive programs are discussed in the following section.

5.1. Incentive program for manufacturers

The incentives awarded to the manufacturer who up-grade the room air conditioner to a certain level of efficiency improvement. The authority should award the incentive to the manufacturers who develop more efficient room air conditioners. This type of incentive has been introduced in the United States which is called the 'Golden Carrot' project [68]. Under this program, the utilities will award some money to a manufacturer develops a significantly more efficient appliance. This new product then should announce publicly. The incentive is eligible for only the units that have been tested and certified by the test procedure used in the particular country.

Another potential complement for further savings is technological procurements. These procurements encourage the manufacturers to commercialize new high efficiency products, starting the market diffusion process that may lead to further savings. The technology procurement can have substantial impact on energy savings by adopting the 'maximum technology' with possible 'technical feasible' and 'economically justified'.

5.2. Incentive program for consumers

Incentive program for consumers is by offering a loan to them to buy efficient room air conditioners in the market that are usually more expensive than the inefficient appliances. Financial incentive for the purchaser of high efficiency room air conditioners can increase the availability and sales of such appliance. Other incentive is to make the consumer interested in energy labels

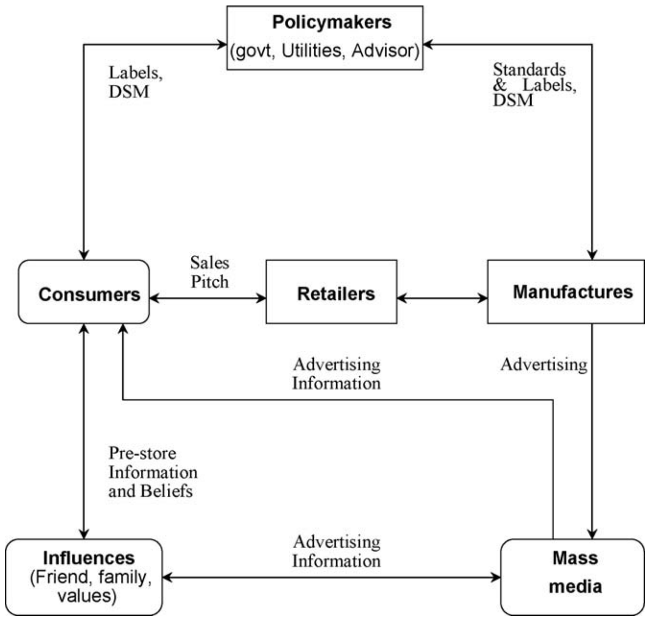

Fig. 14. Actors interact on the purchase environment and decision of the consumers.

by giving nationwide advertising campaign through the mass media such as radio, newspaper and most extensively through the television which has been done successfully in Thailand [69].

The interaction of the player and how its effect the purchase environment, and ultimately, the purchase decision of the consumer are presented in Fig. 14 [61]. Some other possibilities in implementation of incentive programs for the consumers is building code, energy efficiency awareness and soft loan.

6. Conclusion

It has been observed that energy efficiency standards and labels are effective regulations tools to reduce refrigerator–freezers and air conditioners energy consumption. However, an appropriate energy test procedure, which is the base or foundation for any energy efficiency strategy, must be established before energy efficiency standards and labels are developed. Based on literatures it was found that ISO, AS, ANZS, JIS, ANSI, CSA, CNS are the most widely used energy test procedure for testing and rating of these two appliances. However, ISO test standards have been used by many countries around the world compared to other standards.

It was also found that energy efficiency standards can be developed using statistical and engineering/economic approaches. However, a consensus approach developed by US is less widely used energy efficiency standards.

Finally it has been observed that energy guide labels that provide energy efficiency information to the consumers are also an attractive strategy that has been practiced by many countries around the world.

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